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Hiller Aircraft Company

Preliminary Design of a Light Observation Helicopter

Introduction

Hiller Aircraft Company recently undertook the design of a new model light observation helicopter (LOH) for the United States Army. The new aircraft is to replace three aircraft models currently in use. Two are helicopters, the Hiller OH-23 Raven and the Bell OH-13 Sioux, and one is a fixed-wing aircraft, the Cessna O-1 Bird Dog (Exhibit 1). Approximately forty engineers work under a project engineer on this design problem.

An important phase of the preliminary design on new ships is sketching possible overall configurations of the aircraft. The designer must take information from various departments and sketch many possible designs. These sketches are then reviewed by the design team and management. Criticisms by engineers designing control system, rotor system, transmission, etc., lead to elimination of some configurations and refinement of others. As revised sketches become more agreeable to all engineers in the team, more detailed layout drawings are made, leading to the final design. Mr. Alfred Bonnell, Jr., an engineer in Advanced Planning at Hiller, now is

Prepared in the Design Division, Department of Mechanical Engineering, Stanford University by Eugene Echterling under the direction of Professor Peter Z. Bulkeley with support from the National Science Foundation. The cooperation of Edward H. Jacobsen, Alfred Bonnell, Jr., and George Browne of the Hiller Aircraft Company is gratefully acknowledged.
*Revised July 1968 by Richard C. Bourne.

faced with the task of preparing appropriate preliminary sketches for the new LOH design.

Hiller Aircraft Company

Stanley Hiller, Jr., founder of Hiller Aircraft Company, began experimentation on his first helicopter in 1941 at the age of 16. Following successful flights in 1944 of the XH-44, the world's first coaxial rotorcraft, Hiller left his studies at the University of California to devote full time to the newly incorporated United Helicopters, Inc., later to be known as Hiller Aircraft.

Today, Hiller is the world's largest producer of light helicopters, producing approximately 225 ships per year for civilian and military use, domestically and abroad. The U. S. Army is Hiller's largest customer.

The Hiller plant is located at Palo Alto, California, 30 miles south of San Francisco. Approximately 1200 people perform research, administration, engineering, manufacturing, testing, and sales functions at the 61 acre site. An additional office is maintained in Washington, D.C. In early 1964, Hiller became a subsidiary of Fairchild Stratos Corporation, and later in the year Fairchild changed its name to Fairchild Hiller Corporation.

Army Helicopters

The United States Army operates more helicopters than the rest of the world combined. By 1970 it is expected that Army helicopters will outnumber Army fixed-wing airplanes by 8 to 1.

National emphasis on limited war defensive strategy, increased by Communist aggression in Southeast Asia, has accelerated the Army's planned conversion to helicopters for the major portion of its specialized aviation missions. Brig. Gen. J.J. Tolson, director of Army Aviation, reaffirmed the Army's position, "Our experiences in Viet Nam have definitely established

and confirmed what we have been saying. Helicopters have been one of our most valuable assets. As far as hits, we have lost less than two per cent of our aircraft. Our experience compared to the French in Viet Nam is an example; the French were immobile in the field and couldn't fight. The Vietnamese forces today are mobile; they aren't pinned to any one piece of ground."[1]

Maneuverability makes small helicopters practical for reconnaissance work. In addition, helicopters are used for aeromedical evacuation, resupply, communications line laying, and rapid troop movement.

Determination of Need

The decision to undertake design of the new light observation helicopter developed from a series of earlier events which company officials believed showed a definite customer need. Ed Jacobsen, preliminary design chief on the LOH project commented, "We have men called requirements engineers whose job it is to anticipate Army, Air Force, and Navy aviation needs. They travel to military bases, talking to sergeants, generals, pilots, and mechanics. They watch maneuvers and study transportation problems. Often they can forsee military needs before official requirements are stated.

In addition, many of our executives, especially Mr. Hiller, travel a great deal, keeping their fingers on the pulse of military procurement. As a result we sometimes get unofficial reports prior to release of requests for a bid which enables us to begin some preliminary design work before official specifications are available.

"Future needs can also be seen in requests by the military for studies of certain problems. One such request was released by the U.S. Army in 1956 for study of a two-place (meaning two-man capacity) aircraft. Several companies responded with bids for the study contract. Four were accepted, including that of Hiller. The company thought the subject

[1] From an article in the San Jose Mercury, Dec. 20, 1963.

warranted fuller examination and so supplemented the $50,000 study award with an investment of its own. The report, entitled 'Two-Place Observation Helicopter Preliminary Design Study', was published in 1957. It was presented in three parts: Design Analysis, Technical Aspects, and Cost Analysis." A portion of the Design Analysis appears in Exhibit 2.

Following the Two-Place Study, Hiller prepared an unsolicited proposal[2] for a ship called the "Camel". Design of this ship was carried to preparation of a full-sized wooden "mockup" model. Excerpts from the Camel study appear in Exhibit 3. Concerning this proposal, Mr. Jacobsen said, "The Camel was our attempt to show the Army the aircraft they were looking for when they asked for the two-place study. At that time the Army had not yet decided whether it should get a helicopter or a fixed-wing aircraft."

After the unsolicited Camel proposal the Army requested studies from industry for an LOA (Light Observation Aircraft). Both fixed-wing and rotary-wing manufacturers responded early in 1960. The Army's decision was to buy a helicopter. Again, it asked for industry proposals, and the program name changed from LOA to LOH.

Three companies, Hiller, Bell, and Hughes, have been picked by the Army to build competitive prototypes of the LOH. The competition will be based on six months of flight testing of the prototypes. Then one of the three will be chosen for award of a contract for the largest number of aircraft procured by a single order since World War II. Army statements estimate the need to be 4,000 ships. Unofficial estimates range as high as 10,000.

Hiller officials believe that mass production of the LOH will result in a highly saleable commercial helicopter. One Hiller engineer commented, "One of the biggest untapped fields in the helicopter industry is the executive market. From our research and experience with customers we found five major retardants to expansion in this field. These are appearance, cost, speed, and performance; availability of heliports in downtown areas; and limitations imposed by darkness and weather. With the exception of the

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[2] "Unsolicited" is a term commonly applied to proposals not officially requested by the government but prepared for and submitted to the government at company expense.

heliport problem, the Hiller LOH, for the first time, provides a key to this market."

Organization

At the time Hiller received the Army's request for an LOH design proposal, the overall organization of the company was as follows:

- President
  - Executive Vice President
    - Vice President Finance Div.
    - Vice President Sales Div. Marketing
    - Vice President Mfg. Div.
    - Vice President Engr./Research Div.

Preparation of the proposal, although a company-wide effort, was headed by the Manager of Advanced Planning. Ed Jacobsen explained, "The preliminary design is only one aspect of the total proposal effort. Important aspects carried out by other divisions include pricing the design, planning the manufacturing, scheduling the program, and outlining a project organization to execute the expected contract."

Advanced Planning came under the Engineering and Research Division as follows:

- Vice President Engr. and Research Div.
  - Mgr., Advanced Planning
    - Requirements
    - Preliminary Design
    - Publications
  - Chief Test Engineer
  - Chief Technical Engineer
    - Stress
    - Dynamics
    - Weight
    - Aerodynamics
    - Basic Loads
  - Chief Project Engineer
    - Controls
    - Power Plants
    - Elec. and Fixed Equipment
    - Body
    - Rotors and Drives

Ed Jacobsen heads the preliminary design group which, at the peak of its activity, consists of approximately 15 men, many of whom are temporarily assigned from production design groups. Throughout the preliminary design phase, the group meets every Monday morning to discuss progress during the

past week. Frequently, additional meetings are held during the week. Also working with this group are the chief technical engineer, chief project engineer, their group leaders, and men from each of their groups.

It is expected that within about one year Ed's group will release the preliminary design to a prototype design project organization which will be responsible for production of the prototypes to be evaluated by the Army. It is expected that at least $7,000,000 will be invested in the project by completion of the prototype stage.

Preliminary Design

Decisions to be made during preliminary design include establishment of performance targets, selection of vital components such as engine and control system, and choice of an overall shape of the ship. When these decisions have been made and sketches have been selected showing what the ship is to look like, a wood frame mockup will be built for use in working out finer details of the design.

The preliminary design of the LOH will be influenced by the results of the two-place study published in 1957 (Exhibit 2). Although as the preliminary design begins, the specific Army requirements have not yet been released, the company knows from requirements engineers' reports that the helicopter is to be a two-to-four place machine. Thus, the helicopter is in the same size category as ships considered in the two-place study.

At present it is believed that the new LOH should be turbine-powered. Such a recommendation is based on studies which show that turbine-powered helicopters capable of meeting Army needs could be approximately 400 pounds lighter and 15% smaller in overall dimensions than similar reciprocating engine helicopters.

In mid-1957 the Army released contracts to both Allison and Boeing Aircraft for the development of a gas turbine engine suitable for use in a light helicopter. One Hiller engineer commented on the engine development, "Both Allison and Boeing have submitted preliminary drawings of engines.

Although these drawings are subject to later change, they give us enough general information on the engine configuration for our preliminary design." Several drawings of the Boeing engine are included as Exhibit 4.

A great deal of preliminary design is done before the official Army specifications are released. Al Bonnell, who works in Ed Jacobsen's group, commented, "As Ed mentioned earlier, the unofficial reports from our requirements engineers are fairly specific. When the Army's approved specifications do come out, they are very rigidly adhered to. In the specifications, however, requirements are sometimes overlooked that the manufacturer knows are necessary.

"For example, we know that the tail rotor must clear weeds and brush in rough landing areas. We also know that visilibity required special attention since this helicopter will be primarily an observation machine."

Sketching Possible Configurations

One of the key jobs at the present stage of the design is sketching possible overall configurations of the aircraft. Ed's group must produce these sketches. Al Bonnell is one of the designers in the group who does this sort of thing. Before coming to Hiller in 1955, Al worked as a design engineer at North American Aviation. At Hiller, Al has worked on all design proposals for the last eight years. His design function on the LOH project is to produce three-view layout drawings of helicopter configurations which meet the requirements of this particular aircraft. When asked how he proceeds in his sketching, Al explained, "The first things I put on a drawing are the things I know can't be changed. These are given by the requirements engineer and also by a study of previous models. For instance, we know that this ship is to have overall dimensions which are no greater than those of our present model 12-E (Exhibit 5). While I am making my early sketches, other phases of the overall design are being carried out which will naturally affect my thinking. As an example, the group doing parametric analysis says the rotor must be as large as possible, but I must keep it within the known size limits."

In making 1/10 size three-view layouts, Al usually first looks at layouts from previous helicopters to determine the front profile for minimum air resistance. As a result of work with the chief aerodynamic engineer, the cross-sectional shape shown in Exhibit 6 has been chosen. However, Al does not know what the optimum nose and tail configuration will be. His sketches will be important in deciding the shape of these parts of the ship. From his sketches, wind tunnel models will be made. These will be tested. More precise drawings will follow based on results of the wind tunnel tests.

Regarding the overall shape of the helicopter, there are several unresolved areas. One of these is engine location. Since this helicopter is to be primarily an observation vehicle, visibility is a very important consideration. Rearward visibility is affected by engine location. If the engine is mounted high on the helicopter, rear visibility is reduced. If the engine is mounted in a low position, visibility may be improved, but the problem of ducting the engine air intake and exhaust is greatly increased. Al Bonnell commented, "From my standpoint, the primary engine placement consideration is the location of air inlet and exhaust ports." Ed Jacobsen further explained, "We are afraid of ducting problems which arise when we bury the engine too deeply in the ship. We like to keep the inlet and exhaust ducts as short as possible. In addition, we have to make sure that heat from the exhaust does not bother passengers and cargo, fuel supply, or anyone walking around the helicopter. Since this ship must be easily serviceable under front line conditions, engine access is also an important factor."

Ed discussed another consideration in the preliminary design: "All disposable load in a single rotor configuration should be located as near as possible to the center of gravity. This includes passengers, cargo, and fuel. Some companies use movable ballast such as batteries or metal bars which must be shifted as the load is changed. Hiller tries to avoid this since operators sometimes forget to shift their ballast when changing loads. You may recall that about eight years ago at the San Francisco Airport a helicopter (not one of ours) unloaded two passengers and took off before the

operator remembered to shift his ballast to compensate for the shifted center of gravity. The helicopter, shortly after becoming airborne, flipped over and crashed."

Windshield shape inside and top view is also unresolved at present. It will be influenced by decisions regarding personnel seating, entrance and exit, and instrument panel layout.

Compromising

By customary procedure Al Bonnell's sketches will be presented at the meeting of the preliminary design group each Monday morning. At this meeting Al expects his sketches to be subjected to contrasting points of view. Ed Jacobsen remarked, "Aircraft design necessarily involves making compromises, such as weight versus strength and power versus economy. Our design team is composed of specialists in subjects such as powerplants, controls, aerodynamics, and structures. Each of these specialists develops a point of view strongly affected by the problems of his particular area, and often it is necessary for specialists with different points of view to reach a mutual compromise concerning the design.

"We try to solve most of our problems within the preliminary design committee. If, for instance, the transmission man says that the controls are interfering with his layout, I let the transmission man and controls man settle it between themselves, if they can. If they can't reach a decision, I try to decide the matter. This makes me extremely unpopular sometimes. If the decision affects engineering functions other than just design, I of course pass it on to my superiors.

"The preliminary designer plays a vital role in this stage of the design. If his sketches are well thought-out, for instance, conflicts can be minimized. Among the specialists he must work as a generalist, recognizing not only the overall configuration aspects but also the interests of other engineering groups, aerodynamics, production, controls, etc. He should sketch a variety of alternative designs, showing the advantages and disadvantages of each. One immediately tangible symptom of good sketching

is reduction of the number of mockups with resultant savings of valuable time and money."

Wayne Rossiter, who is in charge of producing models and mockups, explained how he proceeds. "Al's drawings are reproduced full size on a blackboard which has one-foot square grids laid out with thin strips of tape. From the side view of the ship we make what we call ½ shell models. These are made of string stretched over cardboard half-sections taped to the blackboard. From these we sometimes have to proceed to mockups made of wood and cardboard. We call this the 'soft' mockup stage."

Soft mockups are usually made to resolve a difference in opinion in a particular area of design. Such differences might include distance between front and back seats, cargo volume, engine accessibility, etc. Ed Explained, "Soft mockups are built of easily changeable components. It will usually take three mechanics and a designer about eight hours to build the components which can be shuffled around to form various configurations of a helicopter. The components of this soft mockup stage are made flexible enough to allow construction of many configurations. The entire ship is not mocked up for every soft mockup. We just concentrate on the area of differing opinion. Once we have the wood and cardboard components made, it takes about four man-days to mockup each configuration."

Final mockups are fabricated of sheet metal and plastic. "They look just like the real thing," Ed Jacobsen emphasized. "Hopefully we can proceed from Al's finished drawings to the hard mockup stage, by-passing the fabrication of soft mockups. This hinges upon whether or not we can satisfy everybody concerned with the drawings of our preliminary design."

Exhibit 1: Hiller OH-23G

Exhibit 1: Bell OH-13

Exhibit 1: Cessna L-19

A portion of the DESIGN ANALYSIS from the TWO-PLACE OBSERVATION HELICOPTER PRELIMINARY DESIGN STUDY (Hiller Aircraft, 1957)

I OPERATIONAL SUITABILITY

The two-place helicopter must possess sufficient performance to satisfy its mission. However, even more important, the helicopter must be *available* to perform its mission. It is recognized that the essential consideration is not the total number of two-place helicopters in the field army, but rather the total number of helicopters *available* to support any one combat mission. The number of helicopters required to support a given fighting strength increases according to the number of helicopters down for maintenance and the length of time necessary to return them to a serviceable status.

To reduce the total number of two-place helicopters required to support a given mission, it is necessary to design the helicopter such that it possesses a high availability characteristic compatible with adverse conditions of combat operation with little reliance on maintenance manpower and facility support. This characteristic can only be achieved by genuine consideration in fundamental design, not only for long service life of components, but to provide rapid and simple servicing and repair.

A. GOVERNING OPERATIONAL FACTORS

Prior to the establishment of design criteria upon which to develop the most operationally suitable helicopter for the mission, it is necessary first to examine the mission, the envisioned concept of employment, operating conditions, and the maintenance support available in the operating area.

1. Mission

The specification indicates four basic missions for the helicopter:

a) Battlefield, route and position reconnaissance to include limited local observation.

b) Command liaison and transportation.

c) Courier operations.

d) Primary training of helicopter pilots.

Since the basic combat helicopter could be easily modified to meet specific training requirements, the training helicopter is not given detailed treatment in this study.

2. Concept of Employment

It is envisioned that the helicopter will be assigned down to the company commander and must be capable of operating in the command post area. In this close proximity to the enemy the helicopter will be supported by the pilot and one enlisted mechanic, indicating that it must be compatible with little or no maintenance support in this area.

It is felt that the company commander, when familiar with the capabilities of the helicopter, will exploit its services to the maximum and that its maximum utilization rate might be 150 to 200 hours of flying in any given month. This is in considerable excess of the capabilities of helicopters presently fulfilling observation-reconnaissance missions, but this high utilization is considered a realistic estimate based upon future concepts of warfare. In the Pentomic Concept the combat situation will be extremely

fluid. Dispersion will place a tremendous strain on conventional means of communications, augmented by the possibility that electronic communications may be ineffective in view of the enemy's technical advances in the science of jamming. All these factors indicate that the unit commander will be more and more dependent upon visual observation, and a flexible, highly mobile means for effecting communication or liaison between command and the troops.

3. Operating Conditions

The command post is assumed to be located in the forward area to facilitate the direction of combat operations. Advantage is taken of terrain for concealment and protection from enemy fire. Therefore, the helicopter operating in the immediate vicinity must be of small size to be able to maneuver in and out of restricted, unimproved positions generally located in any of the world's most difficult topography. Flight operations and maintenance will be conducted under hazardous combat conditions and exposure to the elements of nature. The operating day should be assumed of twelve hours duration, in which flying and maintenance must both be performed. Little night flying will be performed and no night lights will be permitted for night maintenance for security reasons.

4. Maintenance Support

Maintenance functions permissible in this forward area will be restricted to those tasks permitted within the limitations of the mechanic's skill, contents of the mechanic's tool box, and the time available. Operating in the vicinity of the command post will deny the use of any ground support equipment or the erection of facilities due to their vulnerability to enemy actions and the restrictions imposed upon mobility. Typical maintenance permissible in this area would include post-flight and pre-flight inspections, servicing, limited adjustments, small parts replacements, and emergency repairs. Spare parts allowances would be meager and restricted to those items the pilot and mechanic could evacuate in the small helicopter. Periodic inspections would of necessity be performed by a parent aviation unit to the rear which would possess 2nd echelon and perhaps a limited 3rd echelon maintenance capability. To sustain the high utilization rates envisioned, this helicopter must be amenable to the limited maintenance available in 1st and 2nd echelon with little dependence upon 3rd and 4th echelon maintenance manpower and facility support. The dependence upon these higher maintenance echelons must be reduced to spare parts support.

B. OPERATIONAL DESIGN CRITERIA

Having described the governing operational factors to which the two-place helicopter must be suited, it is now possible to discuss the criteria these features establish in its design.

By observation of the operating area (the command post) it appears this helicopter must be small in its geometry and light in weight to permit man-handling of the ship in rugged unimproved terrain to facilitate concealment between flight operations. Since the ship will be in close proximity to the enemy, it must be small enough to permit contour flying to deny enemy identification of the command post or operating site location. From the maintenance point of view, the smaller the helicopter, the easier it will be to maintain in this area.

Since no ground support equipment could be tolerated this far forward, the design must consider the physical limitations of one mechanic. Such limitations would include how much weight one man can lift or carry, how

far a man can reach, and human tolerance in judgment after prolonged periods of open exposure to the elements and the hazards of enemy action.

The design must also consider the limitations of the mechanic's skill, tools, and time available and the limited spare parts available, all of which greatly restrict the maintenance tasks that can be performed in the forward area. This helicopter must in design satisfy these factors and still be capable of high rate utilization.

The above conditions and maintenance limitations demand:

> Maximum accessibility of moving and wearing parts areas to reduce the time, tools and skill requirements for service, inspection, adjustment and repair attendant in routine daily flight operations.
>
> High mechanical reliability and long service life of wearing and moving parts to reduce the frequency of maintenance inspections, repairs and replacement of parts.
>
> Genuine consideration to component phasing and simplification of component, assembly and/or systems installations to permit independent unit replacements and to ease maintenance of installed units.

Adherence to the above principles will measurably reduce helicopter down time for maintenance and increase its availability.

One other important factor affecting aircraft availability which must be resolved in the design state is logistics. Helicopter down time awaiting parts increases according to the length of the supply pipe line, and the number of attrition parts the design possesses. Since the length of the supply pipe line is affected by the enemy's selection of the battlefield, the major logistic control that can be exercised in design is in the number of constituent parts and the rate of their attrition.

The most effective control is in the design and selection of parts to be incorporated in the machine. Emphasis should be placed on reduction in number of sizes and types of static and moving parts to provide *maximum interchangeability of those parts performing the same basic functions.* A typical example is the use of bearings. Conceivably the control system could standardize on one size and type rod end bearing. The various gear boxes could also standardize on bearing sizes and types, and even gears to some extent. Certainly common hardware such as nuts, bolts, screws and attachment fittings could profit from standardization. Standardization and interchangeability also reduce skill and tool requirements for the maintenance support of the helicopter.

Another means by which to reduce the helicopter's vulnerability to logistic down time is to reduce the number of parts within a component. A good example of this case is the main rotor transmission. The helicopter industry uses predominantly the planetary gear type transmission in an effort to reduce weight. From a functional viewpoint, the planetary gear transmission is more efficient by virtue of its ability to transmit more torque for the least component weight.

Yet, compared with a somewhat heavier two stage spur or bevel gear transmission of some four or five gears and bearings, the planetary system has many times more moving parts. Naturally, the probabilities for failure of any one of these moving parts is much greater, which results in increased susceptibility to logistic down time.

Full understanding of the operational factors associated with future employment of this

aircraft directs the designers' effort toward a high performance, high availability helicopter which is small, compact, of lightest practical weight, easily maintainable, and more reliable than existing types.

C. DESIGN PROBLEM: OPERATIONAL SUITABILITY VS. COST

Certainly the above described vehicle can be designed and manufactured today. However, by emphasizing low initial cost the Army in effect compromises the best suited helicopter. Since the helicopter industry is so highly competitive, the low cost specification forces manufacturers to spread out their design investigations to determine how much mission suitability and how much performance the Army is willing to buy. Since the Army has not stated measures of effectiveness upon which the specifications for this study were based, the study must assume several measures which serve to reveal to the Army what various features cost in terms of dollars, performance and suitability.

One of the measures used is operational suitability. Hence, one design approach concentrates on suitability and the effects on cost and performance are measured. Another measure is low initial cost, and its effect on performance and suitability is determined. Still another design approach involves compromise designs which are evaluated to determine the effects on cost, performance and suitability.

To obtain that vehicle best suited to meet the military requirement the Army must place these factors in their proper order in the form of either a technical characteristic or a model specification.

Consider then the interrelation of some of these factors as they are faced in design. An example: low cost and high performance can only be achieved by a low empty weight. It is evident that ease of maintenance and mechanical reliability are the essential ingredients of that helicopter which is the most reliable and the most readily available under the most grueling operating conditions. However, these features frequently add on to the design's empty weight, decrease performance and increase the cost. If the performance specification is felt to be realistic, the designer makes low initial cost, without performance sacrifice, his primary objective. Ease of maintenance and reliability are possibly denied or compromised because the designer cannot tolerate the attendant weight penalties for these features and meet his cost and performance goals.

Maintainability in design is achieved by providing long service life of components (mechanical reliability), accessibility and phasing of components. Long service life of moving or wearing parts can be achieved most generally by reducing stress levels. Reduction of stresses is simply a matter of providing more area or surface against which the forces must work. In turn, more material means more weight in each part. This accumulation of weight of the moving parts increases the empty design weight. However, providing more weight to obtain increased service of components within reason is a most profitable investment. It reduces the frequency of maintenance tasks and reduces the cost of parts consumption per flight hour.

Accessibility to the moving parts areas is most desired to simplify inspection, servicing and repair. This is one profitable way to reduce helicopter down time for such tasks. Fortunately the weight penalties for providing this feature in design are negligible. Most of the designs in this study represent excellent or superior accessibility.

Component phasing, in a sense, is a part of accessibility. Maintenance consideration of component phasing provides for independent unit part, component and/or assembly replacement. Such phasing also greatly reduces inspection and repair problems, effecting a significant improvement to helicopter down time presently experienced for these tasks. It will be apparent upon examination of the various design approaches in this study, that those designs incorporating the most favorable component phasing also pay a weight penalty. This weight penalty is caused by extra shafting, mounts, attachments, isolation systems, and additional case castings.

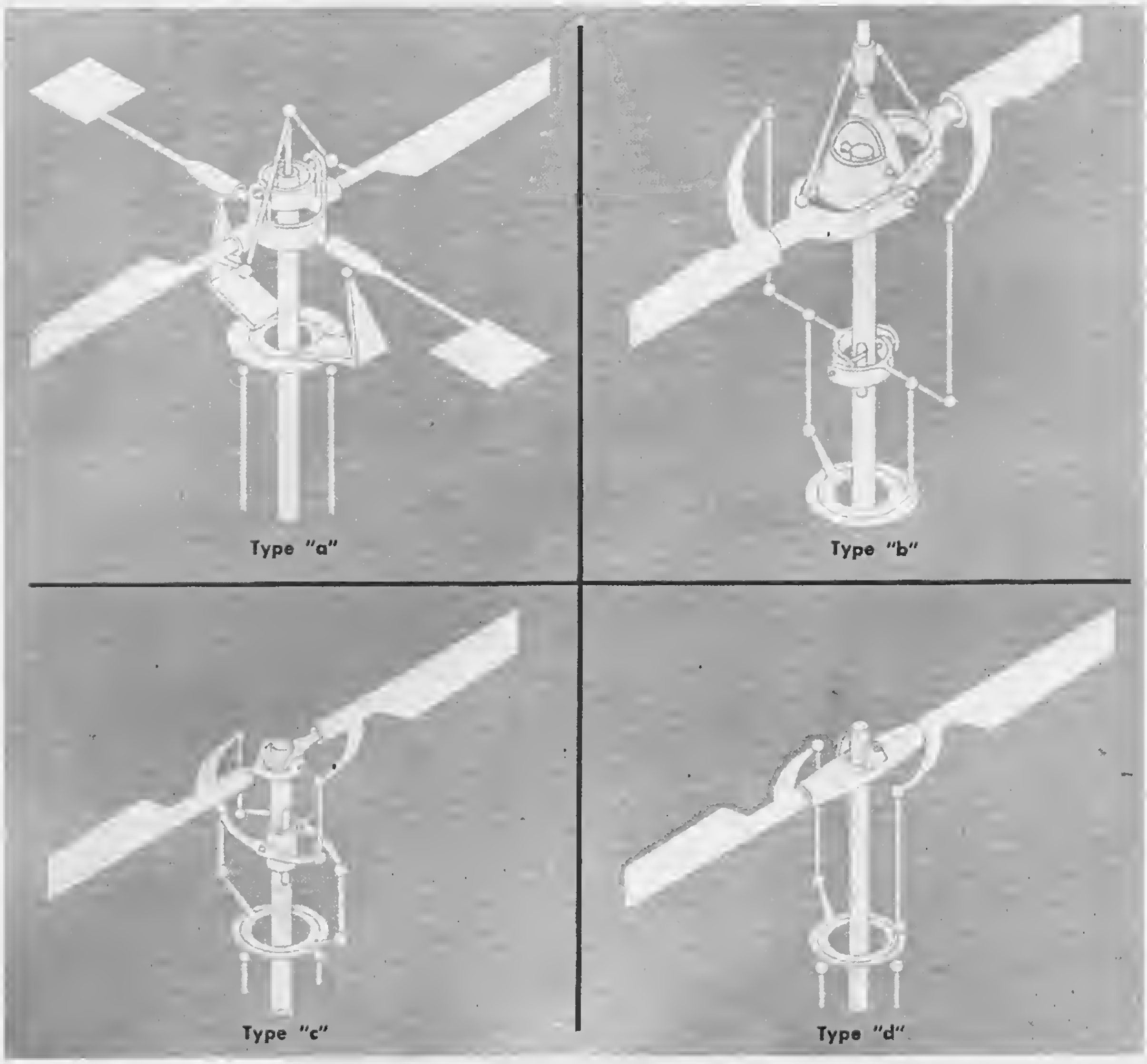
The payment for such features as longer service life and component phasing is a substantial increase in empty design weight. By the time the design engineers add on the additional structural weight to support these features, they may discover that their original engine selection will no longer meet the performance specification. This triggers a vicious upward weight spiral as follows:

> Larger engine induces more torque into moving and wearing parts so their weight must go up.
>
> The larger engine is in itself an added weight factor.
>
> Additional structural weight must be provided for heavier dynamic components and increased engine weight.
>
> The final accumulative effect of providing the Army all of the features known to be desired has an appalling effect on the cost of the design. Since most companies predict manufacturing costs based on dollars per pound of empty design weight it should be apparent why the most maintainable ship is more expensive: it weighs more!

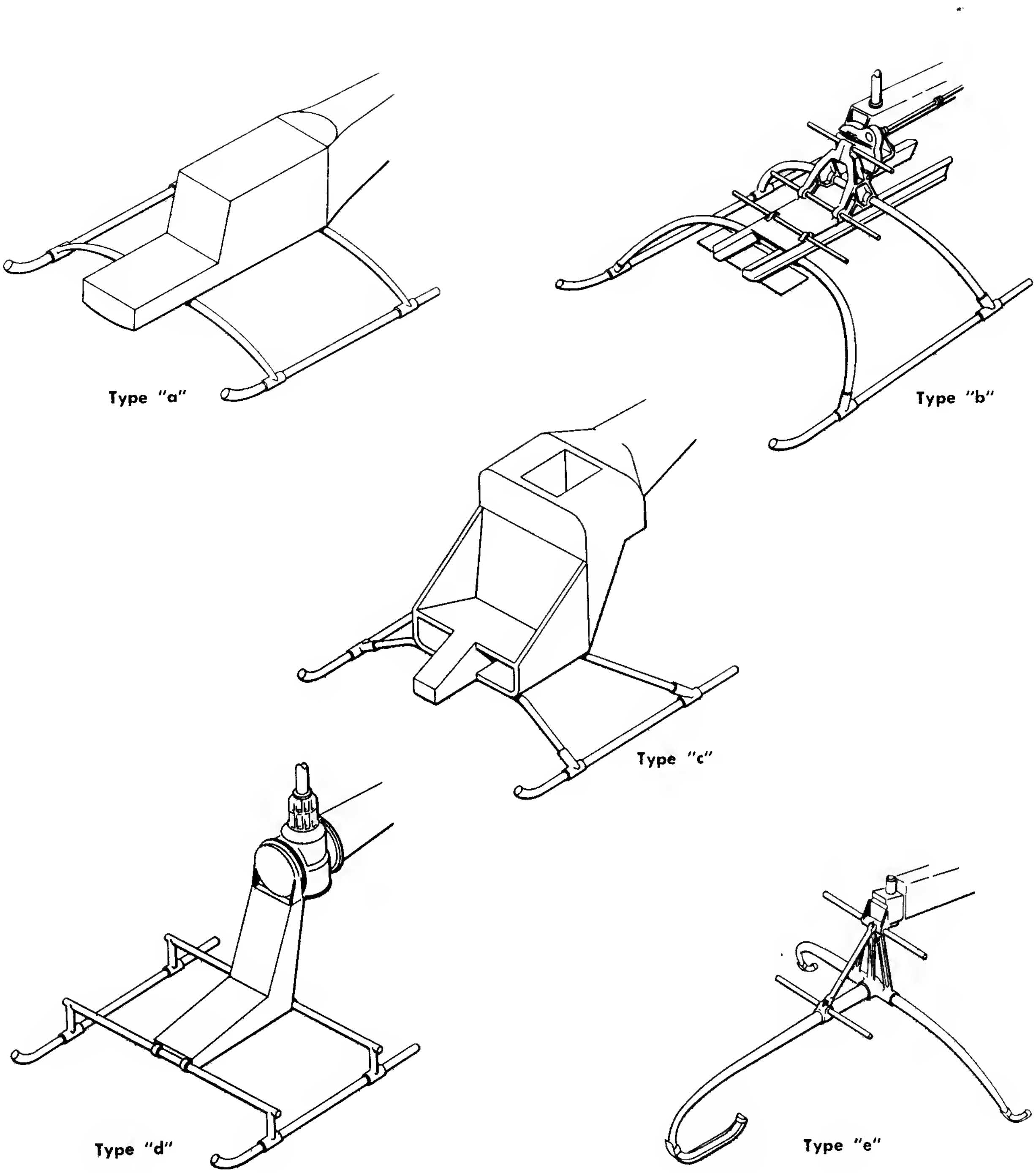
The penalties of weight and subsequent cost increases inflicted by incorporating ease of maintenance in the design can be partly combatted in the design construction approach. The design emphasis is to develop a method of construction of the fuselage which would reduce manufacturing fabrication man-hours. The use of extrusions and forgings to minimize sheet metal lay ups and jigs and fixtures provide a design that is somewhat heavier but reduces the dollar per pound manufacturing costs. This type of construction is also best suited for field repairs. However, tooling and die costs must be paid in advance for this type of construction. Therefore, it becomes impractical to design for this type of construction unless the Army is sure of a substantial production run to justify initial tool and die costs.

A system has been employed in this report which assigns maintainability factors to the configurations studied. These may be observed in relation to associated penalties in weight and cost. The accuracy of the factors is, of course, limited by the ability to represent areas of judgment in numerical terms, but it is felt that attaching relative figures to these advantages and penalties will be most useful to the Army.

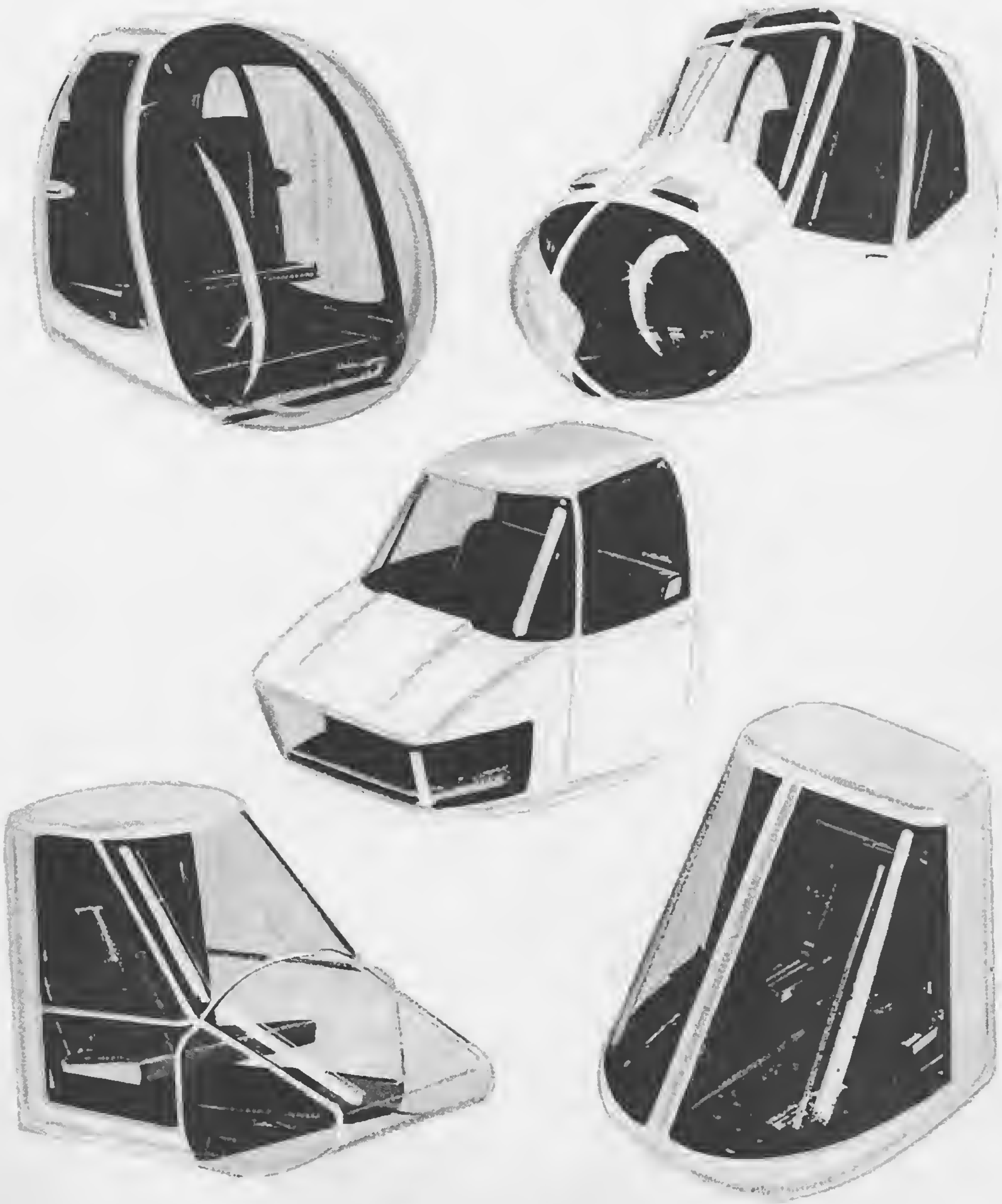
COMPONENT	WEIGHT CRITERIA	COST CRITERIA	MAINTAINABILITY CRITERIA
MAIN ROTOR Hubs, Blades, and Servo Controls	Degree of rigidity, tip speed, disk looding, solidity and rotor radius plus servo control if provided.	Weight and complexity.	Mechanical complexity
TAIL ROTOR Gear Box and Drive	Tail rotor torque, drive shaft length, torsional rigidity, and resonance.	Weight	Mechanical complexity.
POWER PLANT Accessories, Oil System	Engine weight, fixed starting system weight, accessories, % of gross weight; oil system based on requirements.	Engine cost, weight of remainder of system.	Accessibility Removability Overhaul life Engine weight
ENGINE COOLING	Fixed for fon system weight, fixed for ejector system weight.	Quontity of mechonism, quontity of sheet metal.	Mechanical complexity, Accessibility
FUEL SYSTEM	Required capacity, type of system.	Vended parts and weight, instollotion cost.	Mechanical complexity, Accessibility
TRANSMISSION and MAIN ROTOR DRIVE	Maximum rotor torque required, type of transmission, rotor mast length.	Industry estimates based on gear box types plus weight of remainder of system.	Accessibility Removability
STRUCTURE Tail Boom and Landing Gear	Layout evaluation, preliminary stressing.	Manufocturing technique and weight.	
ENCLOSURE	Fixed for structural canopy, fixed for non-structural canopy.	Manufacturing technique and weight.	Installation complexity.
FURNISHINGS	Obtained from vendor.	Unit cost and installation cost obtained from vendor.	
ELECTRICAL AND COMMUNICATIONS	Obtained from vendor.	Unit cost ond instollotion cost obtained from vendor.	Accessibility Replaceability
INSTRUMENTATION	Obtained from vendor.	Unit cost ond installation cost obtained from vendor.	System complexity Replaceability
FLIGHT CONTROLS	System complexity, layout evaluation.	Weight	Complexity Accessibility



POSSIBLE ROTOR SYSTEMS



POSSIBLE STRUCTURAL CONFIGURATIONS



The above enclosures are representative approaches to problems of vision, manufacturability, and maintenance. Shown are some of the variations of the flat wrap, free-blown, integral, and non-integral types studied.

COCKPIT ARRANGEMENT

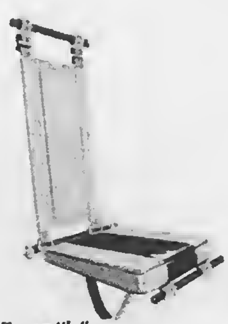
Design of the cockpit portion of the helicopter is governed by personnel considerations and therefore considerable emphasis is placed upon human engineering. Due to the specific nature of the mission, some deviation from established standards is necessary. For example, extensive mock-up studies have proved that personnel arrangements narrower than that advocated by HIAD are entirely practical in this type of helicopter.

As indicated previously, the basic problem of *enclosure* design is resolved by an evaluation of the cost-weight advantages and penalties involved in either combining or separating enclosure and structure. The H-23 is an example of a cab integral with structure while the H-32 represents the separate enclosure. Obviously, a greater variety of manufacturing techniques are applicable in the case of a non-structural cab. In the selection of materials, for example, a non-metallic firewall may be used. *Canopies* considered are *freeblown bubbles* which combine advantages of faired curves and favorable vision, and *flat wrap* in which good optic qualities can be achieved with an added replaceability feature if the sheet size is held to a readily transportable size.

FURNISHINGS ideally include a FULLY ADJUSTABLE SEAT, (TYPE "d") but this operational advantage involves cost and weight penalties. When existing structure can be used also for a seat, a weight economy can be obtained by adding only CUSHIONS (TYPE "a") as in the case of Configuration A (the H-23). A minimum seat for minimum helicopters is produced by the use of FABRIC WEBBING (TYPE "b") or FORMED FIBERGLAS (TYPE "c").

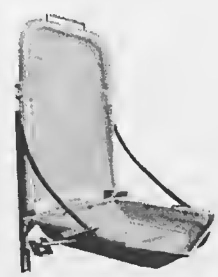
Type "a"—Integral Free-Blown
Type "b"—Non-Integral Flat-Wrap
Type "c"—Integral Flat-Wrap
Type "d"—Non-Integral Free-Blown

Type "a"

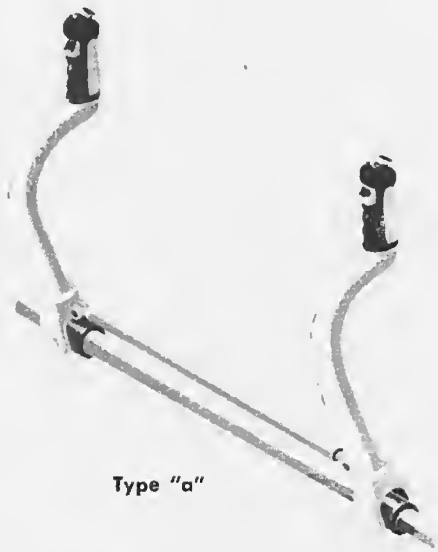


Type "b"

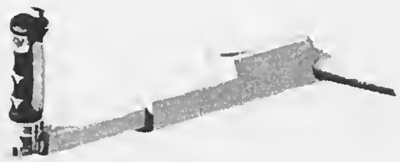
Type "c"



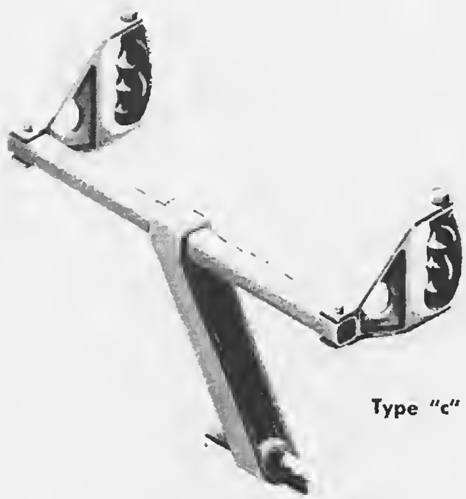
Type "d"



Type "a"



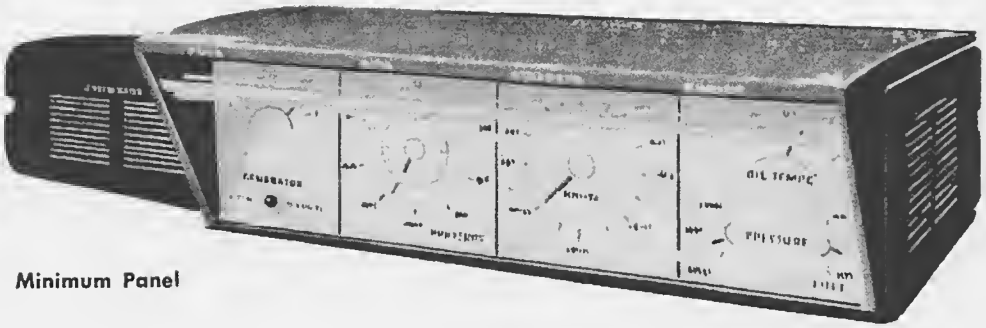
Type "b"



Type "c"

Type "d"

POSSIBLE FLIGHT CONTROL CONFIGURATIONS



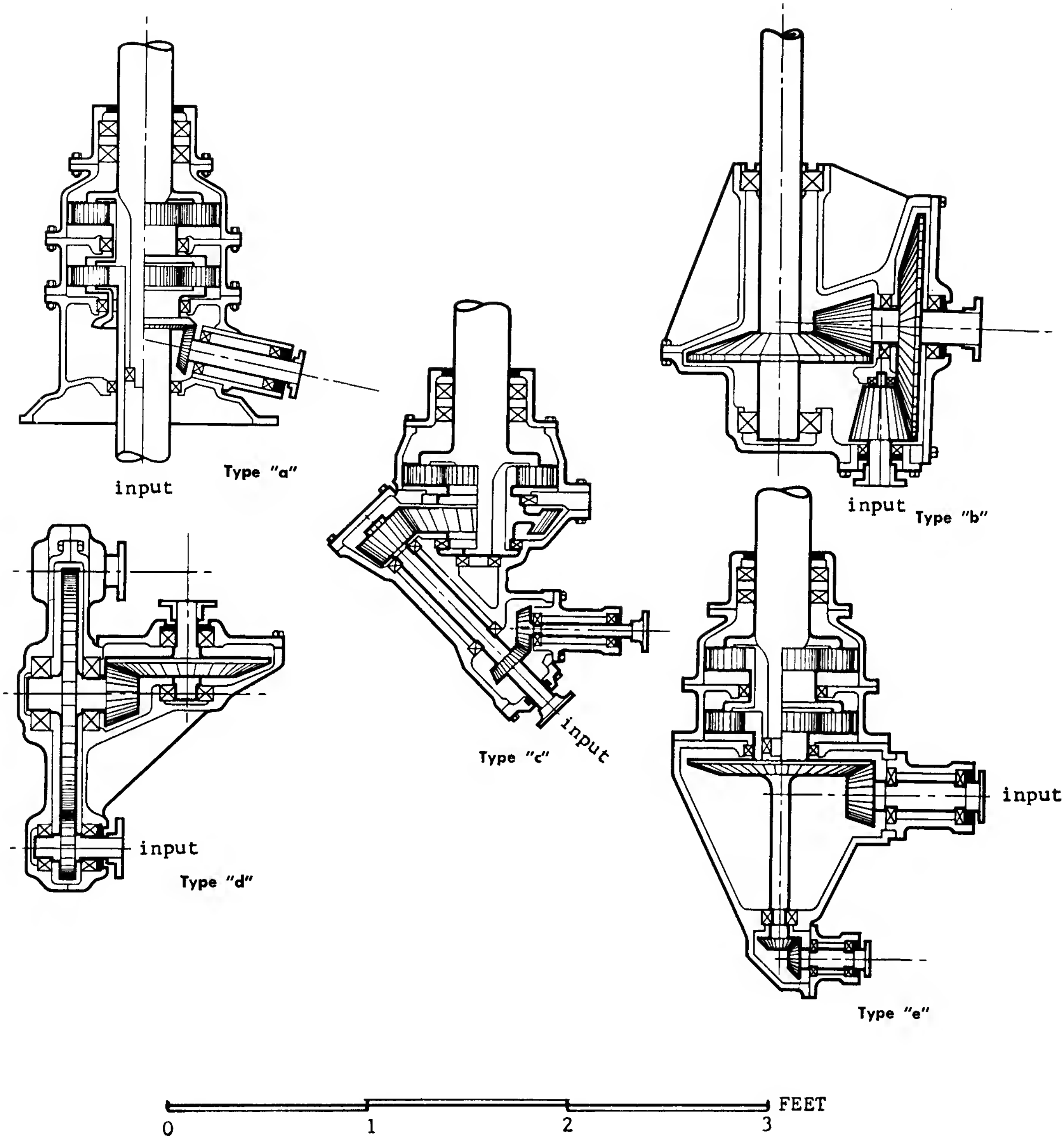
Minimum Panel

INSTRUMENTATION

This is an area in which cost and weight cannot be significantly decreased without a curtailment of function. Any miniaturization effort to save weight would increase cost considerably. Cost and weight savings are realized simply by reduction in the number of high cost purchased items. Two extreme examples are listed: one utilizing the present variety of instruments, the other establishing a minimum number of instruments required on the tactical mission. The latter panel would have to be augmented with additional instruments for the training mission. With the exception of the existing panel used in Configuration A, the instrumentation considered would be equipped with quick disconnects, decreasing the component replacement time involved.

MINIMUM PANEL: The minimum weight, minimum size, minimum cost instrument panel is designed for least obstruction to vision as well as ease of component replacement. It contains only those instruments considered indispensable for flight: engine-rotor tachometer, engine gauge (including fuel and oil pressure and oil temperature) airspeed indicator, fuel quantity indicator, and generator output warning light; plus necessary switches for operation of the helicopter.

FULL PANEL: The full instrument panel contains all the instruments indispensable for flight plus those which give the crew a more complete picture of helicopter operating conditions. These include manifold pressure, cylinder head temperature, carburetor air temperature, altimeter, amp-volt meter, and clock. The full panel is also readily replaceable.



<u>POSSIBLE TRANSMISSION CONFIGURATIONS</u>

EXHIBIT 3:
HILLER CAMEL (ENGINE POSSIBILITIES)

Performance

BOEING T60-BO-2 GAS TURBINE

1. Currently being developed by the Bureau of Aeronautics.
2. Under this program, ratings are:
   Military (30 minutes)—430 HP
   (Standard day, sea level)
   Normal (maximum continuous)—375 HP
   (Standard day, sea level)
3. This engine will supply all the power the transmission, as presently qualified, can use under standard conditions or at higher ambient temperatures and altitudes.
4. Although the specific weight of the T60 is somewhat higher than the T63, the T60 has the advantage of:
   Higher output power
   Operational ruggedness
   Availability six months before T63
   Background of testing under BuAer cognizance
   Reliability and low cost
   Favorable specific fuel consumption
5. The T60 engine is expected to grow to 500 or 525 HP Military rating.
6. Specific fuel consumption is expected to improve with the higher HP ratings.
7. A considerable weight reduction is expected. A 35 pound reduction can be obtained with relatively minor revisions, decreasing weight from 325 to 290. Further reductions are foreseeable which could reduce engine weight to 260 pounds.
8. In conjunction with Boeing and Bendix, Hiller dynamicists have already done extensive analog computer work concerning:
   Control stability for rotor, turbine systems.
   Flight properties of turbine-powered aircraft.

PERFORMANCE SUMMARY

ENGINE	ALLISON T-63			BOEING T-60	
MISSION	Normal Utility	Overload Utility	High Performance Reconaissance	High Performance Reconaissance	Normal Utility
Weight Empty (lb.)	1350	1350	1500	1650	1500
Fuel	300	300	500	700	300
Pilot	200	200	200	200	200
Payload/Endurance at S.L. (hrs)	1000/2.0	1150/1.9	200(obs)/3.7	200(obs)/3.8	1000/1.5
Gross	2850	3000	2400	2750	3000
Max. Speed at S.L. (MPH)*	98	97	107	120	113
Hover Ceiling (ft) (O.G.E., Standard Day)	9000	7000	14,900	16,500**	14,200**
Hover Ceiling (ft) (I.G.E., Army Hot Day)	7100***	4900***	10,900	13,100	9900

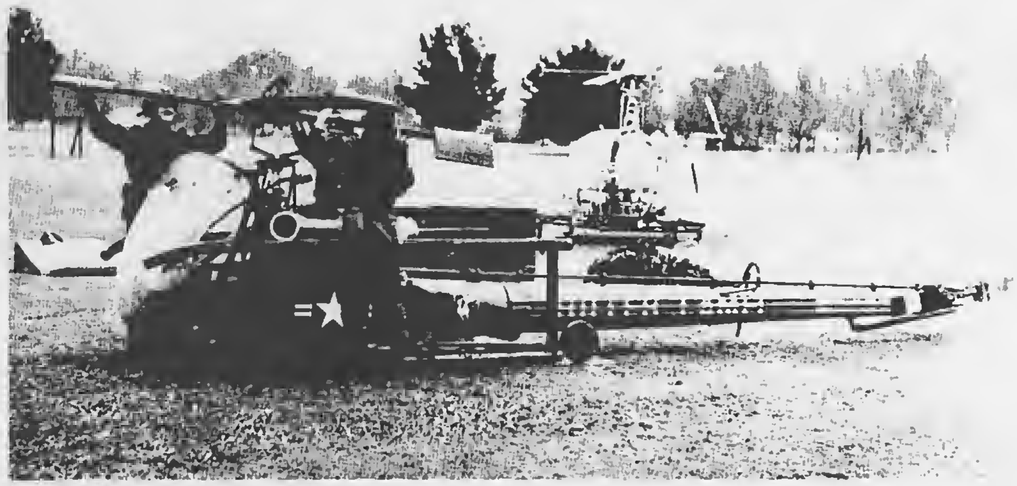
* Based on Modification of Rotor System.
** Compressibility limited.
*** With Water Injection.
T-63 Engine Rating 266/312 HP Except Where Noted. Hover Performed at MIL Power.
T-60 Engine Rating 350/400 HP. Hover Performance at MIL Power.
Endurance Mission Assumes 10% Reserve, 2 Min. Warm Up and Mfgrs. SFC Data Inc. 5%.
Army Hot Day Is 57.4°F Over Std. Temp. Equiv. to 6000-95°F.

ALLISON T63 GAS TURBINE

1. Currently being developed by the U. S. Army.
2. Under this program ratings are:
   Military (30 min.)
   250 HP (Std. day SL to approx. 9300 ft.)
   250 HP (100°F ambient temp. SL)
   Normal (max. continuous)
   212 HP (Std. day SL to approx. 10,400 ft.)
   207 HP (100°F ambient temp. SL)
3. Designed to the latest state of the art.
4. Since the engine carries military and normal power to altitude, as indicated above, the engine power section has considerable growth capability. With improved gear box load carrying ability, development should bring military power into the 300-HP range.
5. Hiller dynamicists have also done considerable analog computer work with the T63.

The unfolding procedure is begun by extending the main rotor blades and pinning the blade drag links.

Like Hiller's YROE-1 Rotorcycle, the unfolded CAMEL is secured by standard (NAS 1333 through 1346) quick-release, positive-lock, single-action pins.



The Hiller Rotormatic control paddles are unfolded and pinned.

One man erects the main body of the CAMEL by turning the hand operated winch, which is permanently installed in the tail boom transition. Quick-release pins lock the main body in flight position.

EXHIBIT - (cont.) HILLER CAMEL

By using the tail boom as a giant jack-handle, the CAMEL body is raised and the landing gear is dropped to flight position. The ground handling wheels and cargo platform act as alternate fulcrums in this operation.

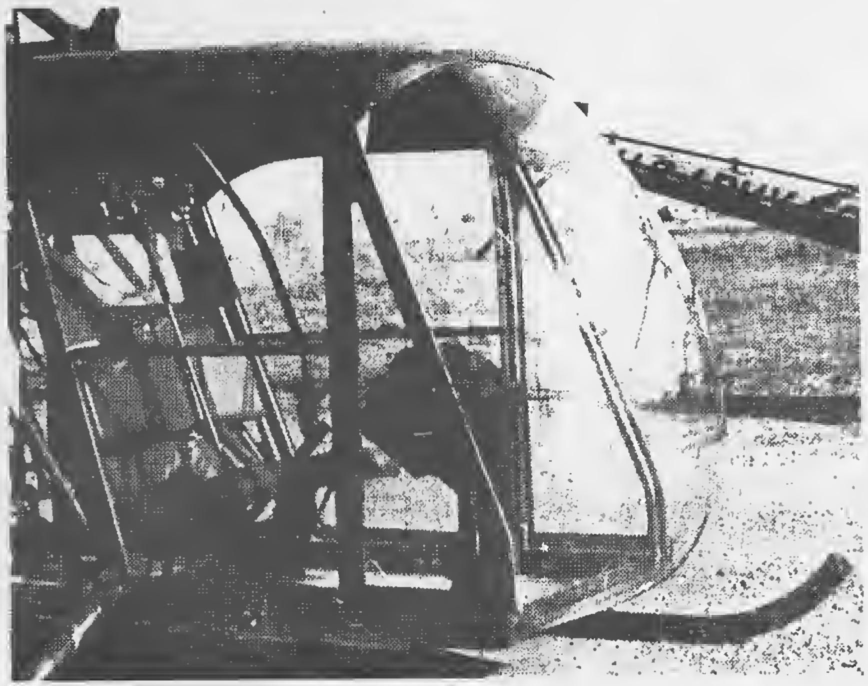
The landing gear is locked in place and the cargo platform secured in the horizontal position. The cargo platform may also be folded and locked against the back of the cockpit to permit slingloading or installation of special equipment, such as wire-laying gear.

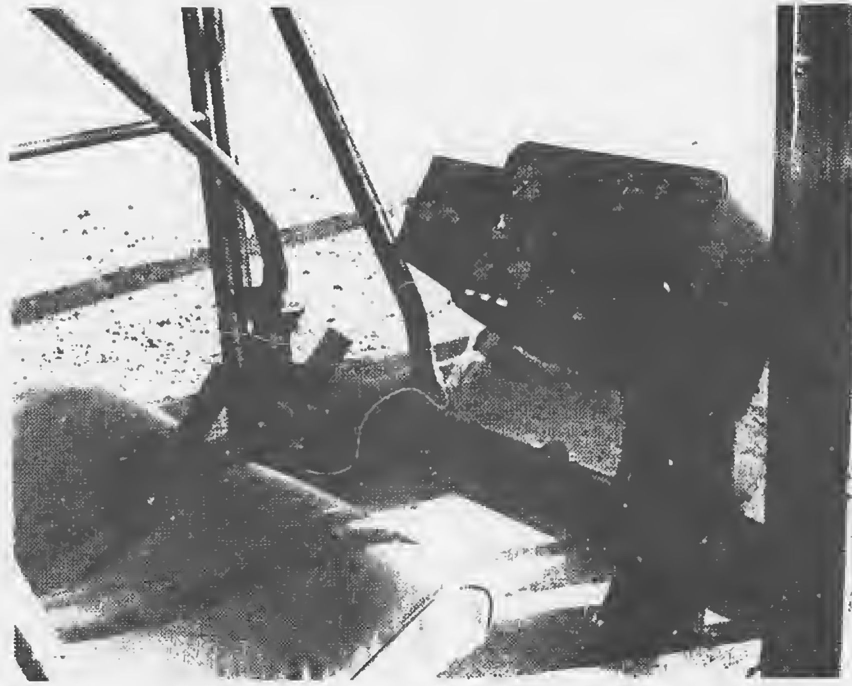
The cockpit roof is secured with standard cowl fasteners. Doors and other accessories may be added at this point.

EXHIBIT 3: (cont.) HILLER CAMEL

EXHIBIT 3: (cont.) HILLER CAMEL

Design Features





TWO-PLACE CABIN

Two seats are permanently installed in the cockpit for the basic two-place configuration. As a two-place helicopter, the CAMEL will effectively meet the requirements of observation, surveillance, target acquisition, fire adjustment, courier, and liaison missions. For reconnaissance missions, special electronic equipment may be readily installed behind the seat back.

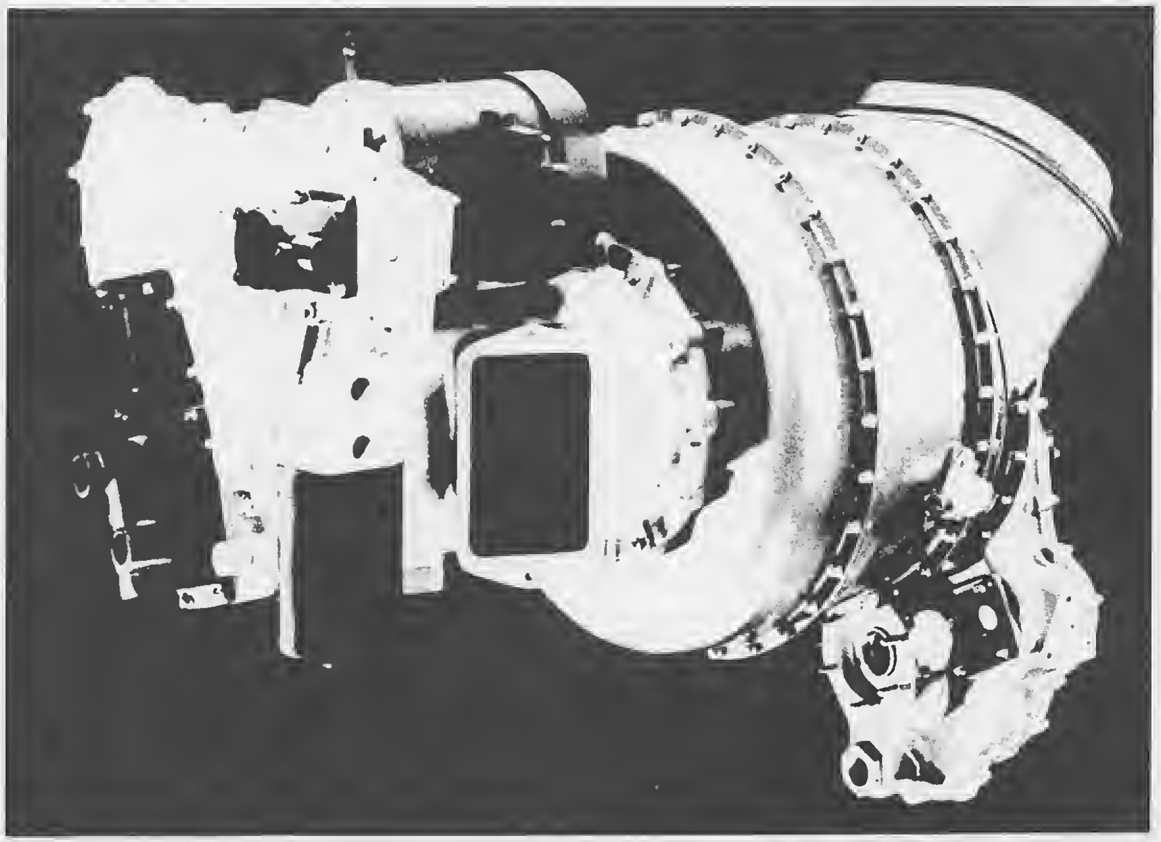
The cockpit was designed to standard HIAD dimensions. This provides greater room for pilot and observer and leaves ample space for radio and electronic gear and an improved foot pedal arrangement. Inertia-reel shoulder harnesses are provided.

The optimum in visibility is obtained by means of a low cockpit, compact instrument console and rear and overhead windows.

The photographs above show the mockup with an overhead cyclic stick installed. In addition to the cost and weight advantages and simplification of the folding arrangement, the overhead stick also makes the cockpit easy to leave or enter and is easily deflected in case of crash. However, since a great number of pilots are now trained to use a floor stick, this alternate type of control is available if preferred.

TRAINING

Although the basic CAMEL is equipped with single controls and an overhead cyclic stick for simplicity, light weight, and foldability, these controls may be replaced with dual sticks for flight training. With doors, canopy, and an auxiliary fuel tank added, the CAMEL remains a lightweight, high-performance, training helicopter. Endurance for the training mission is 4¾ hours.



The engine gas-generator section includes the dual compressor air inlets, the compressor components, the combustor, and the gas-generator turbine. The power-output section includes the power-output turbine, the exhaust system, and the reduction gear assembly with front and rear drive pads. The accessory section, located at the front of the engine, includes the main fuel control, the lubrication pump, and drive pads for the starter-generator, tachometer generator, tachometer generator, and spare accessory. Maximum engine dimensions are: length, 32.10 inches; width, 16.30 inches, and height, 23.64 inches. Engine dry weight is 125 pounds.

Power is delivered from the output turbine through an offset, two-stage, helical reduction gear to front and rear drive pads located below the engine centerline. Sufficient clearance is provided under the engine to accommodate a driveshaft forward to the helicopter transmission. The output-section tachometer generator pad and the output-section governor are located on either side of the forward output drive pad. A torque-sensing element providing a hydraulic pressure signal is included in the reduction gear train.

Engine-mounting pads are provided in a vertical plane on each side of the output reduction-gear housing in the vicinity of the output drive pads. A single mounting pad intended to take vertical and side loads is located beneath the engine between the compressor inlets.

EXHIBIT 4 - Engine Data: Boeing Model 535

INSTALLATION FEATURES

The principal installation features of the Model 535 are outlined below to provide a basis for discussion of the helicopter installation. Model 535 installation drawings contained in the enclosed document D4-1754 should be referred to for more detailed specifications and visualization of the engine configuration.

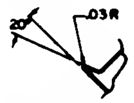
The Model 535 engine uses a three-point suspension system. Two main trunnion mounts are located with a common lateral axis directly above the power takeoff pads. This arrangement allows for quick, positive alignment of the engine with the helicopter rotor drive shaft. The third mount will carry side and vertical loads only and is located on the underside of the compressor housing.

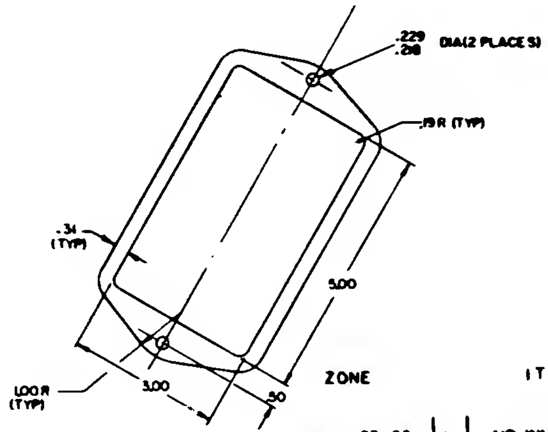
Rectangular bifurcated air inlets are cast into the sides of the compressor housing. They are canted forward to form a 60-degree angle with the engine centerline.

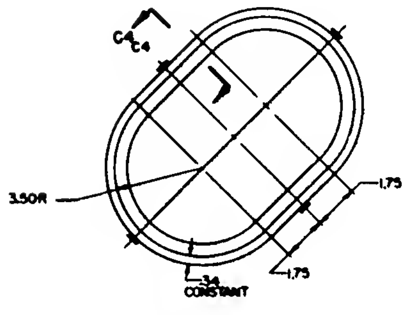
The rectangular cross section and forward canting of the inlets minimize the overall installation width requirements for the LOH induction system. The air-inlet ducts attach to the engine inlet flanges by two standard bolts per flange.

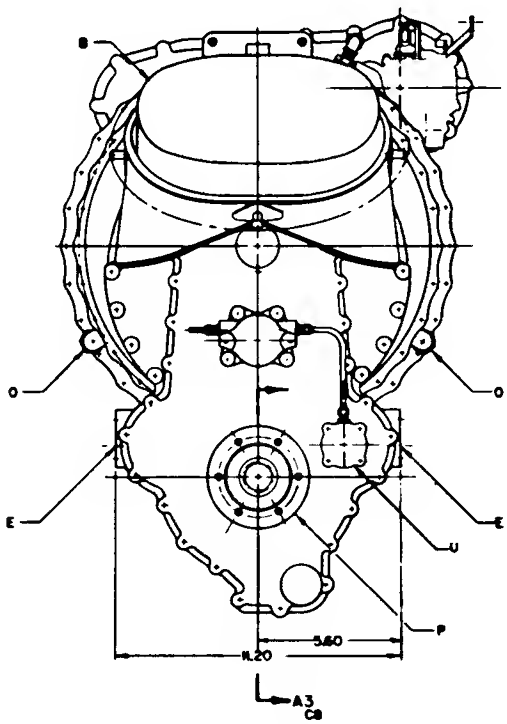
The Model 535 inlet configuration results in a substantial reduction in the highly directional high-pitch compressor whine associated with straight axial inlets; this produces benefits in reduced sound-proofing, crew fatigue, and susceptibility to detection.

A single ovalized rear exhaust outlet discharges the exhaust gases aft and upward. The exhaust duct and outlet are completely shrouded to prevent external leakage of combustible liquids from reaching the hot parts of the engine and to contain exhaust-system fires. A quick-disconnect flange attachment is provided on the aft end of the shroud. The shroud is of sufficient strength to allow cantilever mounting of short exhaust extensions to the atmosphere or into an exhaust eduction system.









ZONE		ITEM
A6 C5 C6	A	AIR INLETS
B4	B	EXHAUST OUTLET
B5 B7 C5	C	CENTER OF GRAVITY
A6	D	FORWARD ENGINE MOUNT
A3 A4	E	REAR ENGINE MOUNTS
B5	F	FUEL PUMP & GAS GENERATOR FUEL CONTROL
B5 C5	G	STARTER GENERATOR DRIVE PAD
B6	H	TACHOMETER DRIVE PAD
C6	I	SPARE ACCESSORY DRIVE PAD
A7	J	OUTPUT GOVERNOR
A7	K	TACHOMETER DRIVE PAD
A7	L	OIL FILTER
A7	M	OIL & SCAVANGE PUMP
C5	N	IGNITION UNIT
A3	O	IGNITOR PLUGS
A3 A7	P	OUTPUT DRIVES
C5	R	OIL FILTER BYPASS VALVE
C5	S	OIL PRESSURE REGULATING VALVE
A4	T	TORQUEMETER
A3	U	TORQUEMETER PUMP
B4	V	EXHAUST SHROUD QUICK DISCONNECT FLANGE
A5 A7	W	MAGNETIC DRAIN PLUGS
B7 D5	X	GAS GENERATOR POWER LEVER
A7	Y	OUTPUT CONTROL LEVER
B4	Z	EXHAUST THERMOCOUPLE HARNESS
D5	AA	FUEL INLET CONNECTION
B6	AB	FUEL PUMP DRAIN
A5	AC	COMBUSTOR FUEL DRAINS
A5	AD	FUEL PRESSURE CONNECTION
A7	AE	OIL PUMP INLET CONNECTION
B7	AF	OIL OUTLET CONNECTION
B6	AG	OIL PRESSURE CONNECTION
A4	AH	TORQUEMETER PRESSURE CONNECTION
B7	AI	OIL VENT CONNECTION
B5	AJ	BLEED AIR CONNECTION
D5	AK	IGNITION UNIT CONNECTION
A5	AL	FUEL NOZZLE MANIFOLD
A5	AM	FUEL FLOW DIVIDER

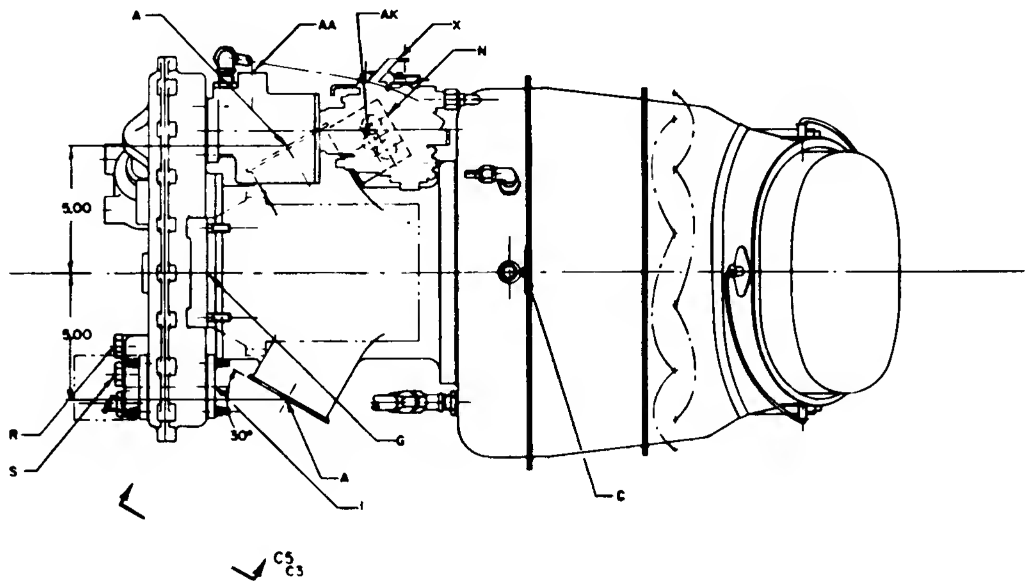
ENGINE INSTALLATION
BOEING
MODEL 535
PRELIMINARY

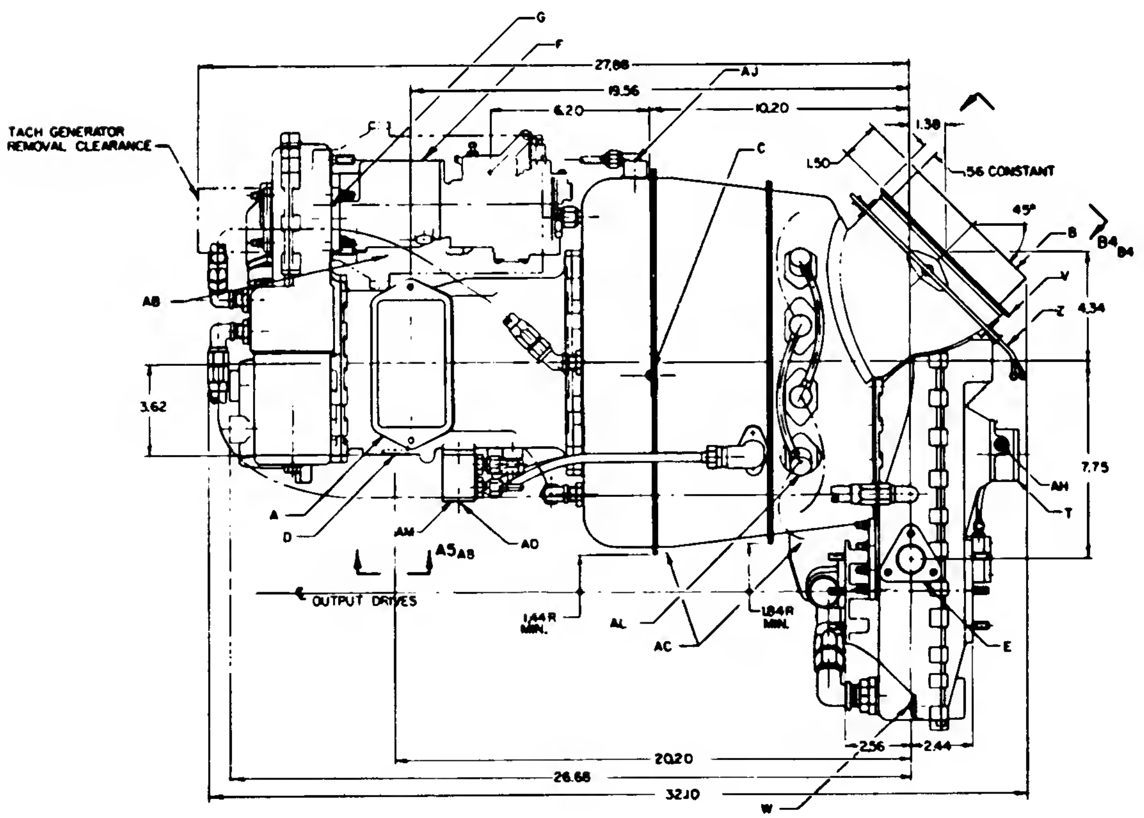
45-2936

3 2

EXHIBIT 4 - Engine Data

(Page 3 of 6)





6 5 4

EXHIBIT 4 - Engine Data: Boeing Model 535

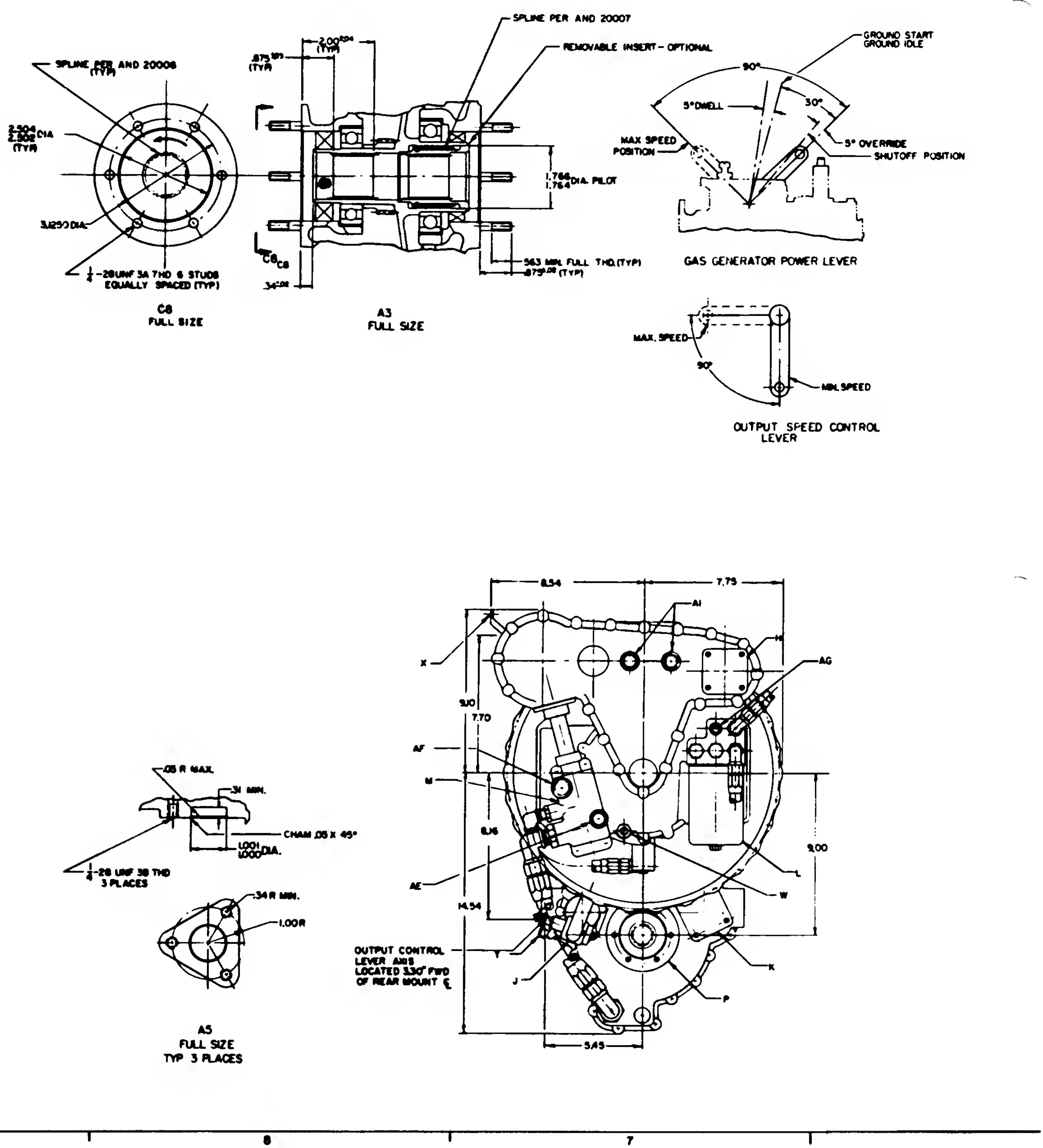


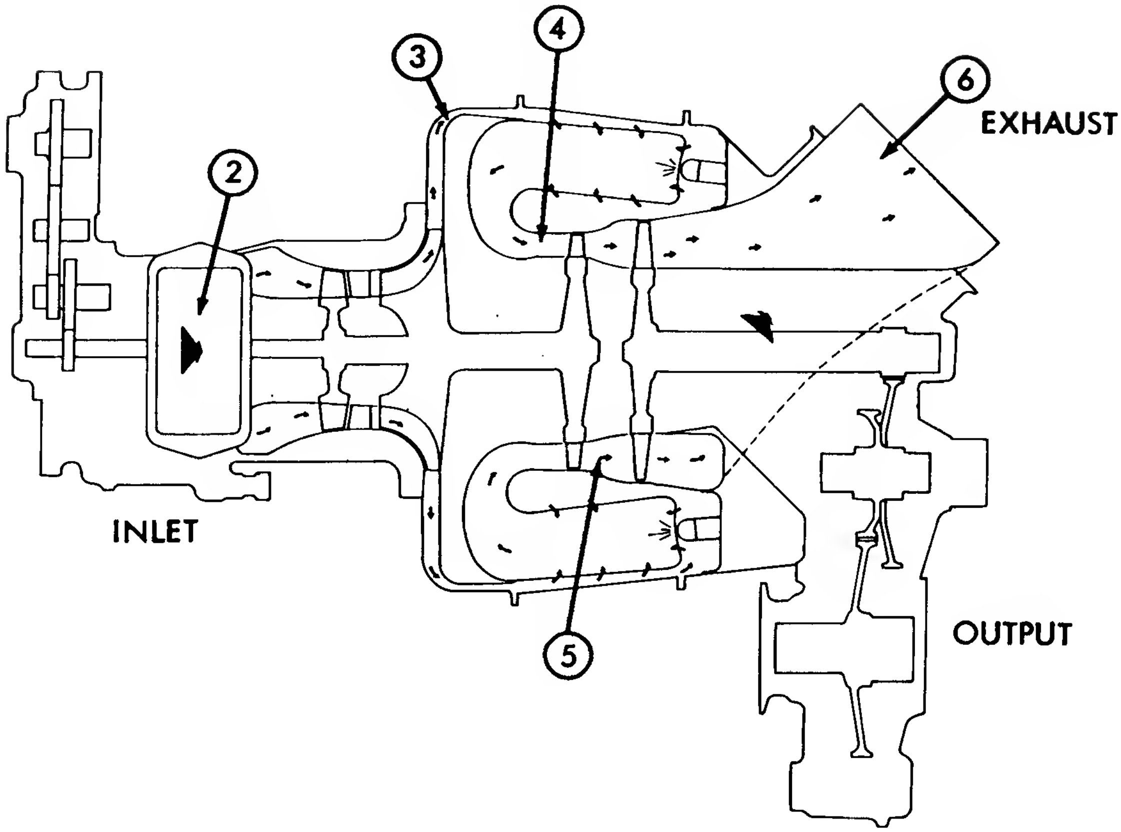
EXHIBIT 4 - Engine Data: Boeing Model 535

(Page 5 of 6)

Engine Data: Boeing Model 535

NOTE :

ENGINE CAN BE MOUNTED IN ANY POSITION.



(2) ENGINE INLET

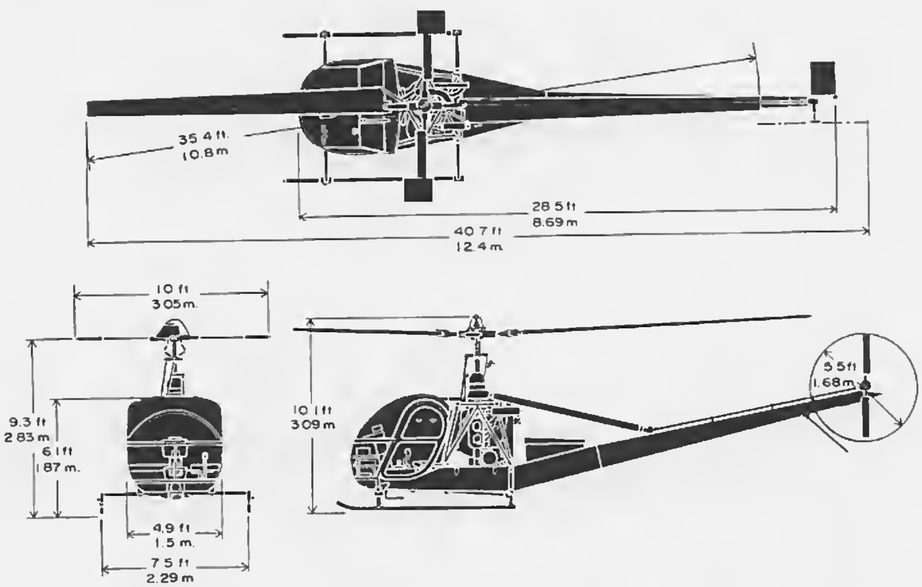
(3) COMPRESSOR OUTLET

(4) GAS-GENERATOR TURBINE INLET

(5) POWER TURBINE INLET

(6) EXHAUST GAS OUTLET

Figure 24 GAS FLOW DIAGRAM



PERFORMANCE SUMMARY

Mission weight	lbs	2800	2240	kg	1270	1018
Empty weight	lbs	1759	1759	kg	799	799
Useful load	lbs	1041	481	kg	472	218
Maximum permissible speed	mph	96	96	km/hr	155	155
Cruise speed	mph	90	92	km/hr	145	148
Range at S.L.	mi	225	250	km	362	402
Endurance	hrs	3.2	3.5	hrs	3.2	3.5
Maximum rate of climb	ft/min	1290	2030	m/s	6.55	10.3
Vertical rate of climb	ft/min	740	1720	m/s	3.76	8.73
Hover ceiling OGE	ft	5800	12300	m	1768	3749
Hover ceiling OGE*	ft	7200	13500	m	2195	4115
Hover ceiling IGE	ft	9500	15700	m	2896	4785
Hover ceiling IGE*	ft	10800	16900	m	3292	5151
Service ceiling	ft	15200	19800	m	4633	6035
Service ceiling*	ft	16200	22000	m	4938	6666

* With high compression piston kit, 100/130 octane fuel

EXHIBIT 5 - Hiller Aircraft Model 12-E

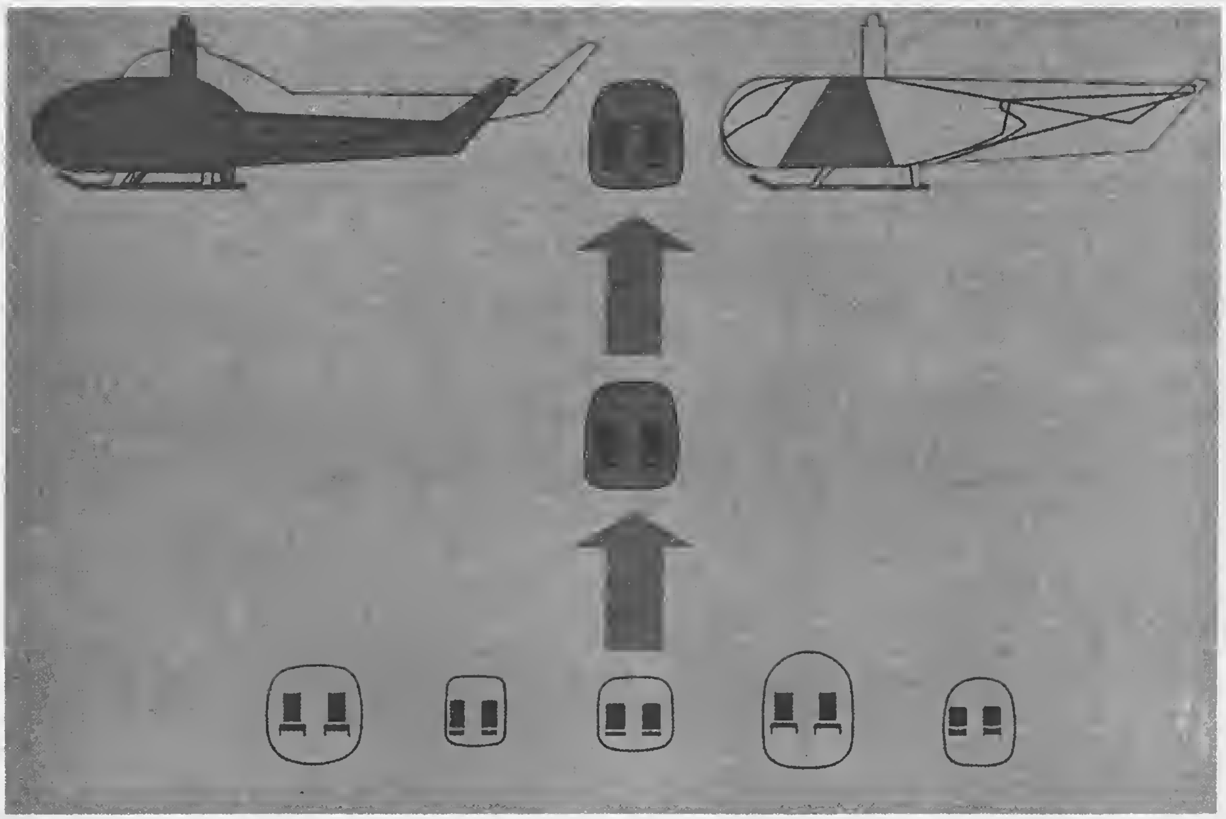
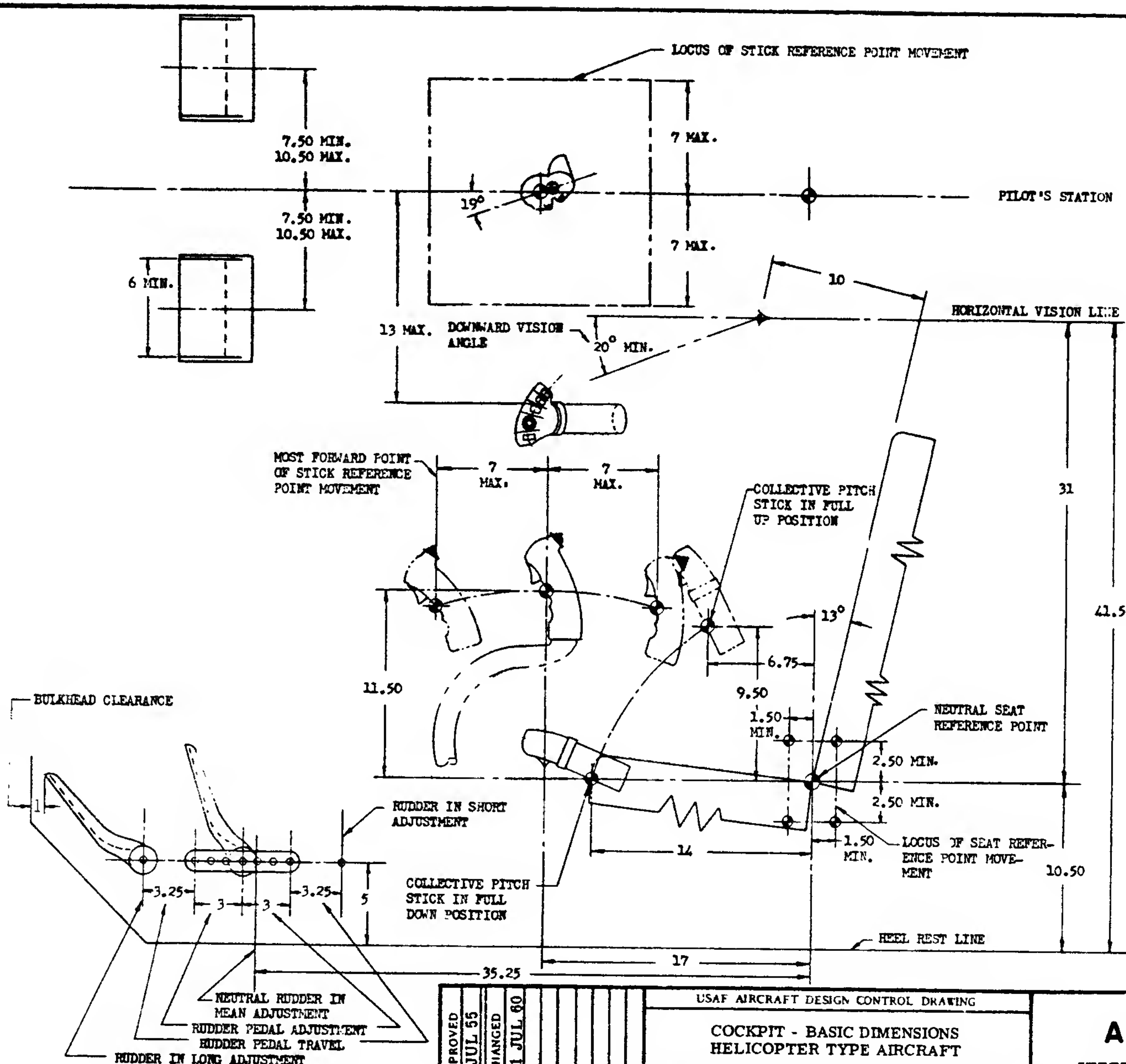


Exhibit 6: Cabin Cross-Section Chosen For the LOH

9. ADEQUATE CLEARANCE SHALL BE PROVIDED TO ALLOW UNRESTRICTED OPERATION OF THE RUDDER PEDAL THROUGHOUT THE FULL RANGE OF TRAVEL.
8. THE PEDAL "BRAKE OFF" ANGLE WITH RESPECT TO THE VERTICAL SHALL REMAIN CONSTANT THROUGHOUT THE ENTIRE RUDDER PEDAL TRAVEL.
7. THE COLLECTIVE PITCH STICK TRAVEL SHALL NOT EXCEED 12 INCHES FROM FULL DOWN POSITION OF THE GRIP.
6. THE SEAT SHALL BE PROVIDED WITH FORE & AFT AND VERTICAL ADJ. INDEPENDENT FORE & AFT AND VERTICAL ADJ IS DESIRABLE. HOWEVER, DIAGONAL ADJ IS ACCEPTABLE.
5. RUDDER PEDAL ADJUSTMENT SHALL BE IN INCREMENTS OF 1 INCH OR LESS.
4. THE STICK REFERENCE POINT IS DEFINED AS THE POINT AT WHICH THE PILOT'S SECOND FINGER IS IN CONTACT WITH THE FORWARD FACE OF THE STICK GRIP.
3. REFERENCE SPEC MIL-B-8584 FOR BRAKE PEDAL ANGLES AND DIMENSIONS.
2. ALL MEASUREMENTS ARE BASED UPON THE SEAT REFERENCE POINT AT THE CENTERLINE OF THE SEAT IN THE NEUTRAL POSITION.
1. DIMENSIONS SHOWN ARE FOR SHORT RANGE PILOT'S SEAT CONFORMING TO SPEC MIL-S-5822, TYPES A-9 AND A-10.



APPROVED	CHANGED	USAF AIRCRAFT DESIGN CONTROL DRAWING	AD I
1 JUL 55	1 JUL 60 (2)	COCKPIT - BASIC DIMENSIONS HELICOPTER TYPE AIRCRAFT	SHEET 2 OF 4
		DRAWING FOR INFORMATION ONLY. CONTRACTOR SHALL NOT REFERENCE BY NAME OR NUMBER ON HIS DRAWINGS.	SUPERSEDES AD1 - 1 APR 60

EXHIBIT 7 - Preferred Helicopter Control Layout.

ENGINEERING CASE LIBRARY

ECL 21R*

Hiller Aircraft Company

Preliminary Design of a Light Observation Helicopter

Introduction

Hiller Aircraft Company recently undertook the design of a new model light observation helicopter (LOH) for the United States Army. The new aircraft is to replace three aircraft models currently in use. Two are helicopters, the Hiller OH-23 Raven and the Bell OH-13 Sioux, and one is a fixed-wing aircraft, the Cessna O-1 Bird Dog (Exhibit 1). Approximately forty engineers work under a project engineer on this design problem.

An important phase of the preliminary design on new ships is sketching possible overall configurations of the aircraft. The designer must take information from various departments and sketch many possible designs. These sketches are then reviewed by the design team and management. Criticisms by engineers designing control system, rotor system, transmission, etc., lead to elimination of some configurations and refinement of others. As revised sketches become more agreeable to all engineers in the team, more detailed layout drawings are made, leading to the final design. Mr. Alfred Bonnell, Jr., an engineer in Advanced Planning at Hiller, now is

Prepared in the Design Division, Department of Mechanical Engineering, Stanford University by Eugene Echterling under the direction of Professor Peter Z. Bulkeley with support from the National Science Foundation. The cooperation of Edward H. Jacobsen, Alfred Bonnell, Jr., and George Browne of the Hiller Aircraft Company is gratefully acknowledged.
*Revised July 1968 by Richard C. Bourne.

Instructor's Notes

The Hiller Aircraft case has been popular in the introductory course at Stanford, where it has been used for instruction in conceptual design. Students have been asked to select between various system components, and to sketch several design configurations. The assignments are designed to require about 24 hours of a student's time, making the case a 2-3 week assignment. Class time has been spent on discussion to establish criteria for the design problem, as well as on sketching practice and short graphics assignments.

The case is structured around a proposal being developed by Hiller Aircraft for the Army concerning the design of a new light observation helicopter. Background material on the need for the craft follows a brief company description. The last part of the case discusses the function of the preliminary design group at Hiller. Exhibits include excerpts from a previous Hiller design study, alternatives for several important components, and information on the turbine engine which will power the craft.

The task of organizing several components into a system which satisfies certain broad objectives will be a new experience for most students. It should probably be emphasized to them that there is no perfect solution. Furthermore, it cannot even be expected that their results will be very good! The objective of an assignment of this type for first year engineering students is not for them to design the best light observation helicopter in the world, but rather to stimulate them to think and visualize spatially in the context of an actual design problem.

For the first assignment, students might be asked to submit two-view sketches showing different general arrangements of the major systems, including structure, engine, transmission, rotors, seating, controls, instrumentation, and fuel supply. For the purpose of this assignment these components need be described only in outline, except that inputs and outputs should probably be identified on such components as engine and transmission.

Students should be encouraged to make their several designs as different as possible, to combat the natural tendency to seize on one idea, put several different facades on it, and thus possibly neglect a better basic scheme.

Suggested Assignment:

You are to assume the role of Al Bonnell for your work on this project. You are to produce 5 sketches of 5 different helicopter configurations. Each sketch should include three views of the ship, showing general location of power plant, main rotor, tail rotor, transmission, structure, enclosure (including seats, cargo volume, controls, instrument panel), and fuel system.

Be prepared to defend your suggested designs, showing advantages and disadvantages of each. From your 5 preliminary sketches, produce one free-hand 3-view layout drawing representing what you feel is the best combination of features found in your 5 preliminary designs. Your drawings, which will be reviewed by both engineering and management people, should be self-explanatory, easily readable, and neat.